Significant Cost Improvement of Li-ion Cells Through Non-NMP Electrode Coating, Direct Separator Coating, and Fast Formation Technologies

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Johnson Controls, Inc.

Project ID #: ES133

2014 DOE Vehicle Technologies Program Review
June 9, 2015

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Overview

Timeline

- Start: October 2011
- Finish: March 2015
- Final report to DOE: April 2015
- Percent complete 100% completed(1)

Budget

- Total project funding
  - DOE: $3.67M
  - Johnson Controls and sub-recipients: $3.67M
- Funding received in 2014: $1.39M
- Funding for 2015: $0.44M

Barriers

- Concentration polarization of dry electrode affects high current rate capability
- Dry cathode manufacturability
- High self-discharge rate on integrated cell

Partners

- Entek Membranes
- Maxwell Technologies
- University of Wisconsin – Milwaukee

(1) Tasks complete as of Mar 2015

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Objectives - Relevance

Project scope

- Significant cost improvement of Li-ion manufacturing:
  - Non-NMP electrode coating process
  - Direct coating separator
  - Fast formation
  - Integrated cell design

Objectives

- Develop integrated cell with non-NMP electrodes with direct coated separator
- Develop dry electrode formulation, design and process for PHEV application
- Develop an additive and new formulation for process improvement for aqueous cathode
- Develop an automated roll to roll lamination process for large cell production
- Validate new fast formation process

Addresses Targets

- 50% manufacturing cost reduction
- Better than 90% performance of integrated cell compared to baseline's performance

Impacts

- The performance of integrated cells have been improved so that it has achieved 92% performance compared to baseline which is very promising results.
- The cost of cell has achieved 50% reduction, the technologies developed here have great potential for the future Li-ion battery to expand the market.

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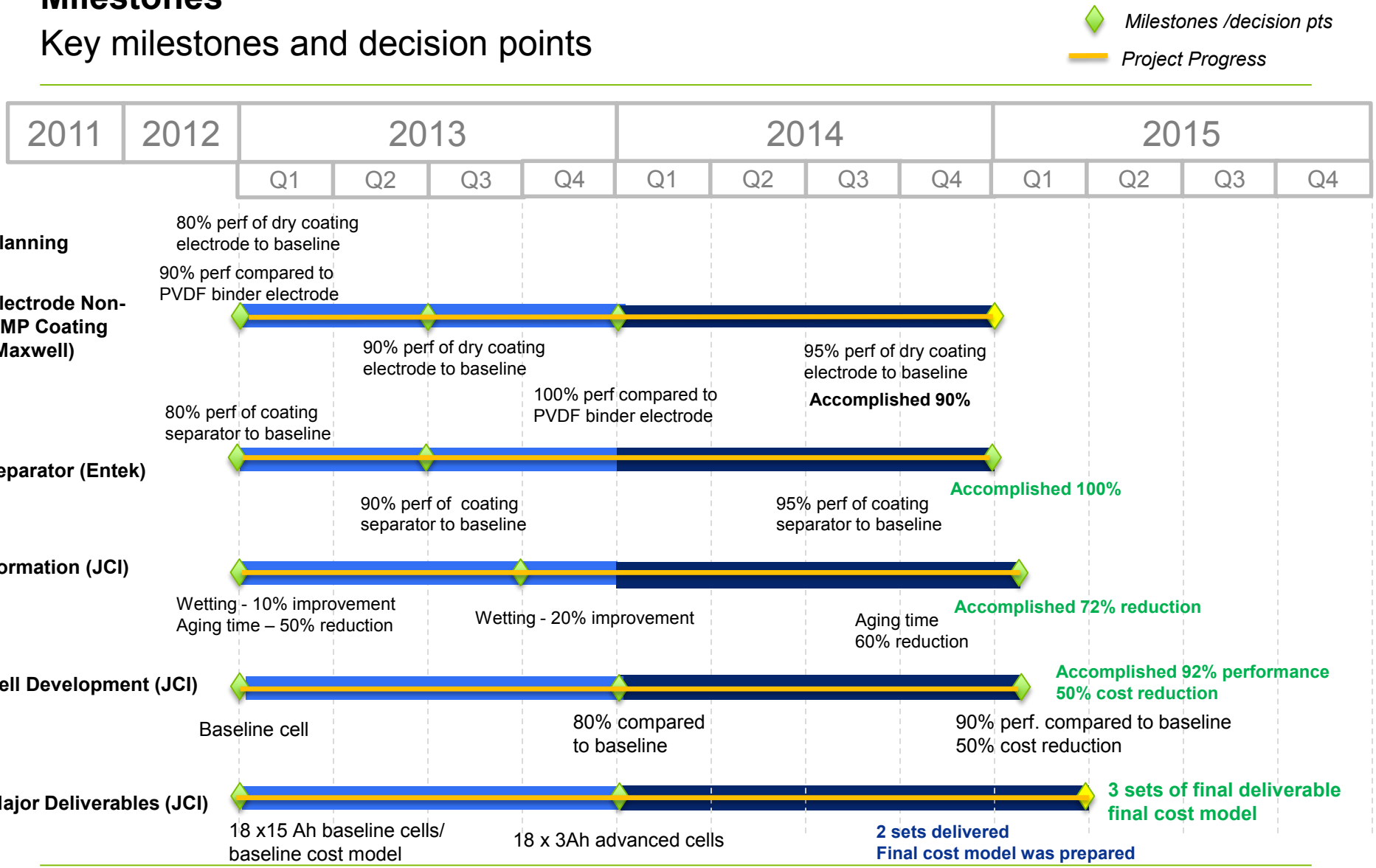
Milestones

Key milestones and decision points



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Approach

Dry coated electrode

- Develop process with optimized electrode formulation and design
- Improve the micro-structure of electrode for high rate capability performance
- Develop the process of automated pilot line for large cell build

Aqueous cathode binder

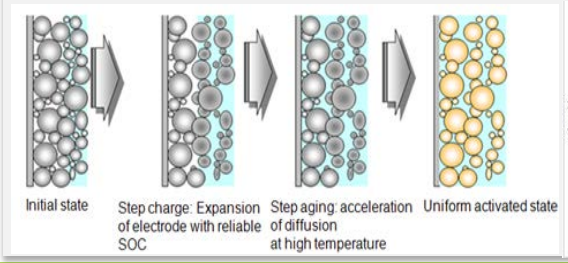
- Develop new cathode binder which is both electrochemically and chemically stable
- Develop an additive and new formulation for process improvement
- Investigate corrosion prevention methods and risk mitigation to allow for aqueous solvent manufacturing
- Perform trial run on production line

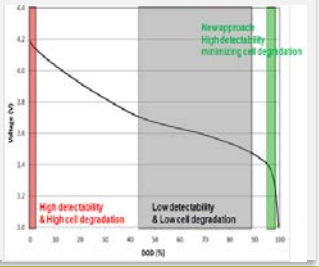
Direct-coating of separator material on Li-ion electrodes

- Formulation changes to improve porosity for Si/PVDF direct coated separator
- Laminate a free-standing separator on anode
- Develop roll-to-roll process for scale-up to large format cell build improving lamination strength and thickness variation

Fast Formation

- Develop new activation and detection process to improve cell uniformity, accelerate detection time, and minimize cell degradation





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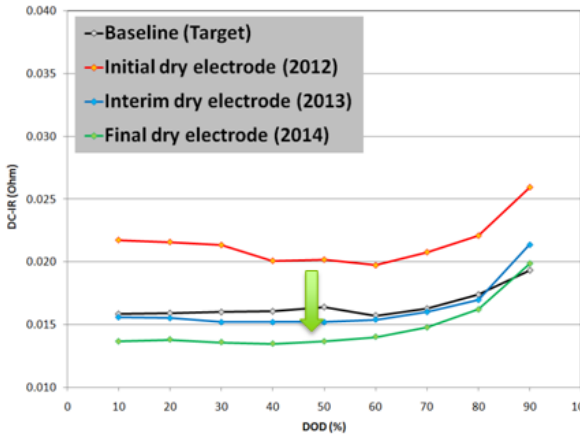
Technical Accomplishments
Dry Coating Electrodes

Dry Coating Electrodes

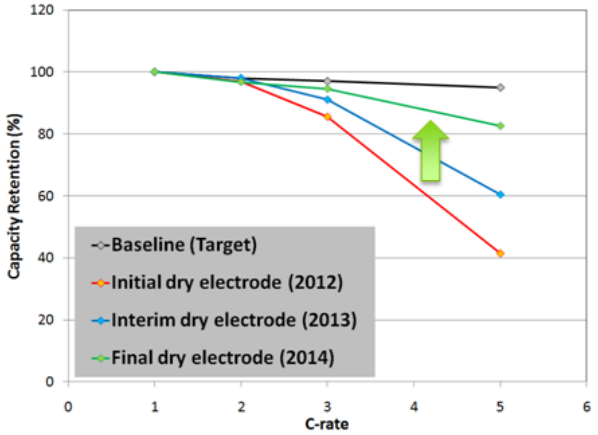
- The results for the optimized process and design of dry electrodes demonstrate much improved performance
- 31% lower ASI compared to initial dry electrode, and 15% lesser ASI than the baseline
- The rate capability has been improved progressively and the final dry electrode shows twice higher rate capability compared to initial dry electrode
- The micro-structure of dry electrode has been improved and verified using 3D-SEM and EMPAEMPA characterization

Highlight
91% performance and 53% cost reduction compared to wet coating

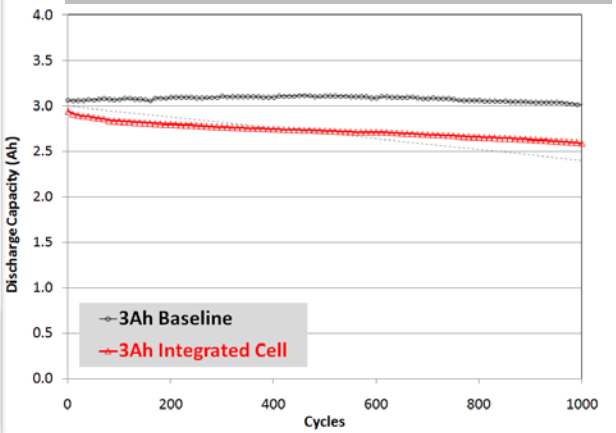
DC-IR thru HPPC

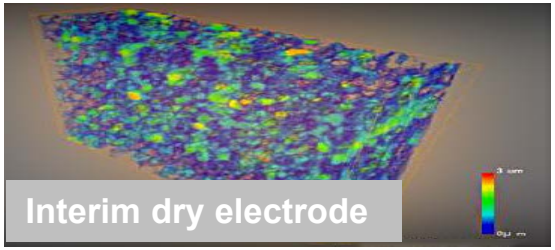


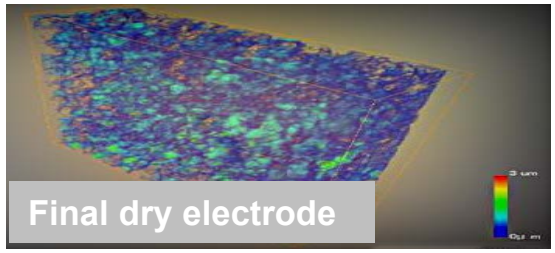
Rate capability



Cycle life (1C/1C 100% DOD)







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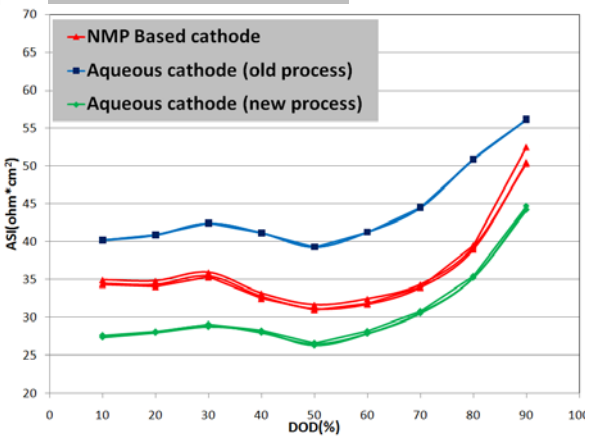
Technical Accomplishments
Aqueous Cathode

Aqueous Cathode

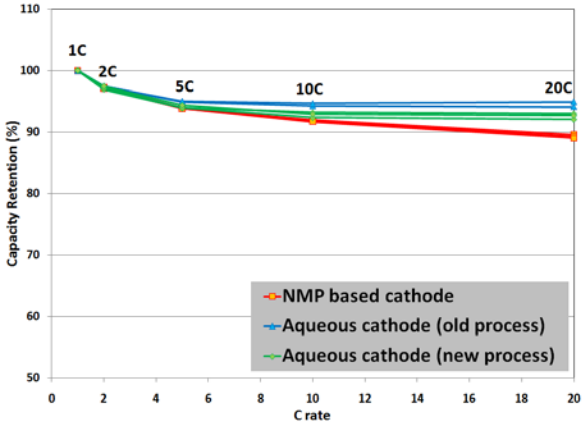
- Excellent cycle and calendar life results
- The rate capability and power performance have been improved through optimizing formulation with additives to improve slurry dispersion
- Investigated corrosion mechanism and proved the reliability of aqueous cathode cells with NMC chemistry
- The results of aqueous cathode cells with new process which developed for power application show excellent performance and uniform electrode quality

Highlight
97% performance and 3.5% cost reduction compared to NMP based electrode process

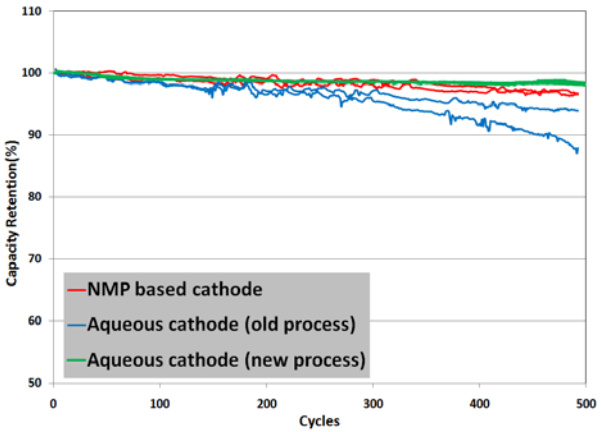
ASI thru HPPC

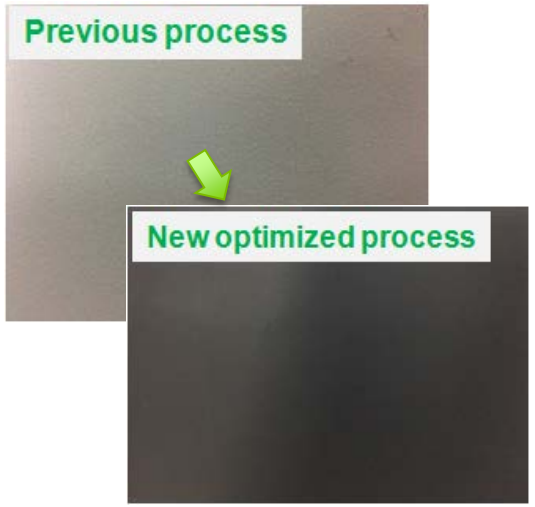


Rate capability



Cycle life (2C/5C 100% DOD)





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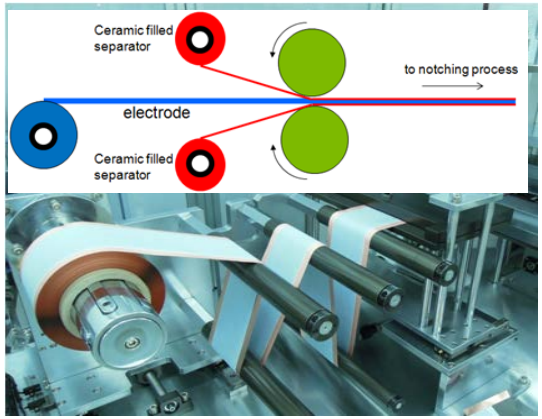
Technical Accomplishments
Direct Coated Separator

Direct Coated Separator

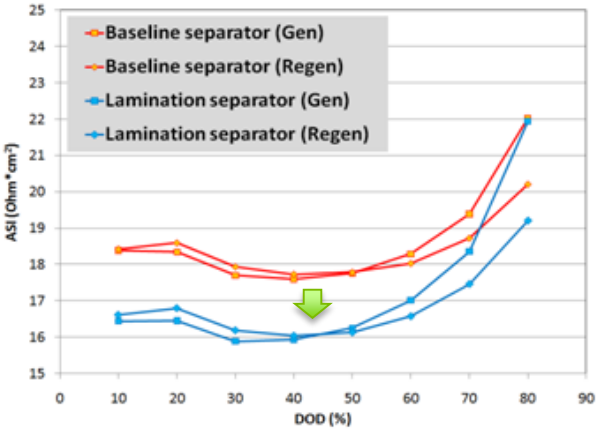
- There are three technologies for direct coated separator: solvent coating, dry coating and lamination
- The lamination gives the most promising results of the three methods
- 10% lower ASI and 20% higher retention capacity at 5C rate compared to baseline
- Minimized thickness variation of continuous roll-to-roll lamination
- Eliminated the zig-zag separator process and speed cell build time from 1 to 3 cell per minute

Highlight
100% performance and 56% cost reduction on assembly process

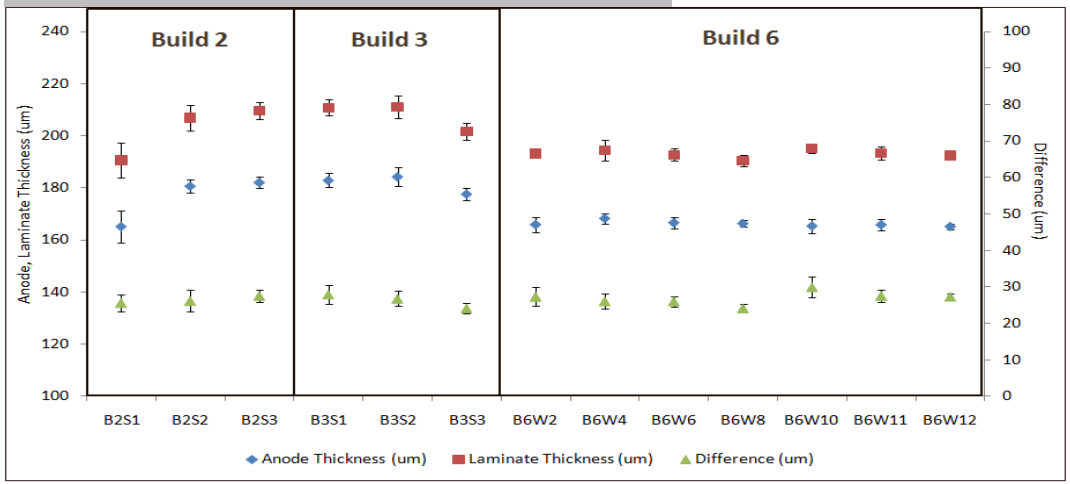
Separator laminated anode



ASI thru HPPC



Thickness variation during cell builds



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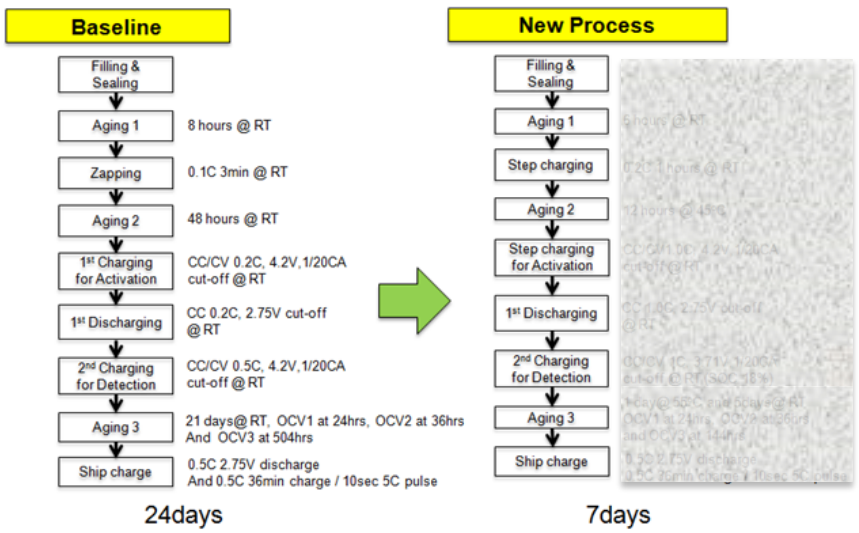
Technical Accomplishments
Fast Formation

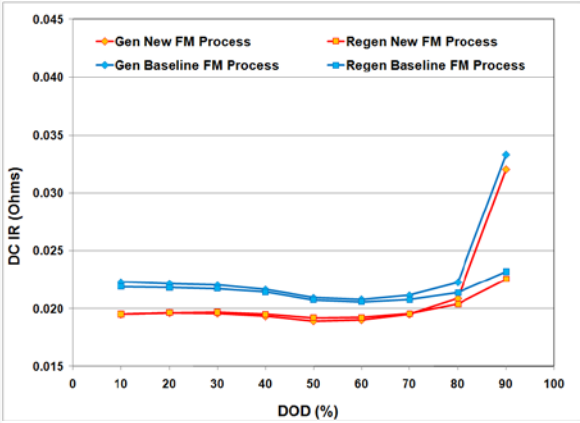
New Fast Formation

- New fast formation needed to activate cells uniformly and to detect defective cells sooner
- Developed new activation process to improve cell uniformity and performance using step-charging and step-aging process
- Developed a new detection process at low SOC to accelerate detectability minimizing cell degradation
- The results of new formation cells show little capacity loss and better variation and performance.

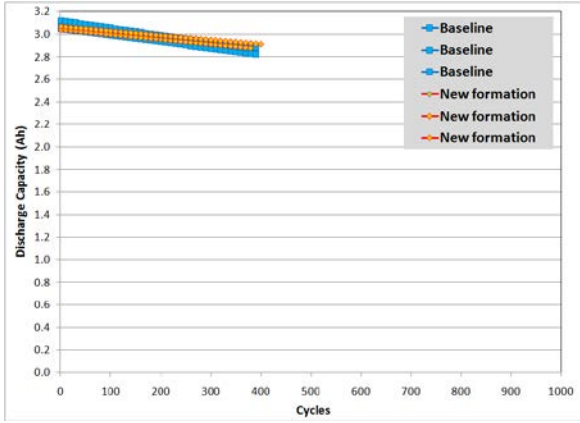
Highlight
24 days(Baseline) → 7 days



Final validation: DC IR thru HPPC



Cycle life (1C/1C @ 45°C)



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Technical Accomplishments
Cell Development

Integrated Cell Development

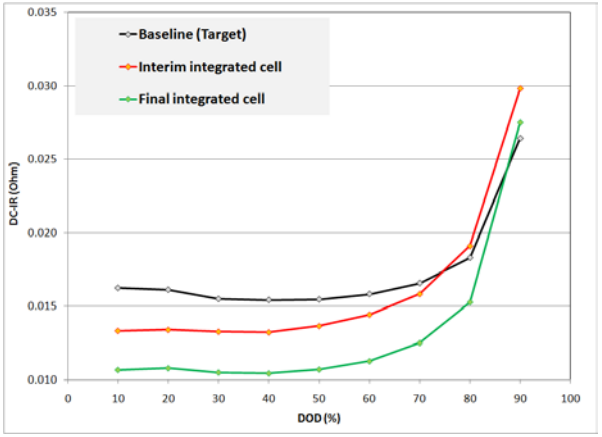
- Cell design for PHEV application
- Integrate the new technologies into developed 3Ah/15Ah cells
- Integrated new technologies and built cells on JC-UWM pilot line
- 30% lower DC impedance compared to baseline
- 27% higher rate capability at 5C discharging compared to the interim integrated cells, and similar performance with baseline cells

Highlight
92% performance and 50% cost reduction compared to baseline

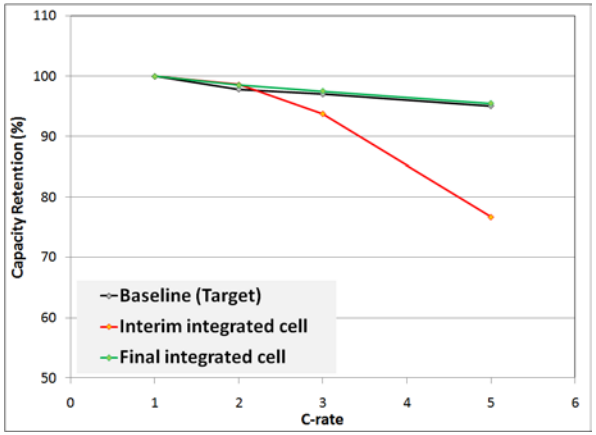
Integrated cell design

Item	Unit	Baseline		Dry Electrode					
				Initial		Interim		Final	
		Cathode	Anode	Cathode	Anode	Cathode	Anode	Cathode	Anode
Active material	%	95	95	88	93	88	93	88	93
Loading weight	mg/cm^2	15.5	8.4	20.4	10.6	18.8	10.6	16.6	8.5
Thickness	um	131	141	165	168	151	186	140	148
Density	g/cc	2.8	1.33	2.82	1.43	2.87	1.32	2.65	1.3
Capacity	Ah	3.1		3.3		3.0		3 / 15	

DC-IR thru HPPC



Rate capability



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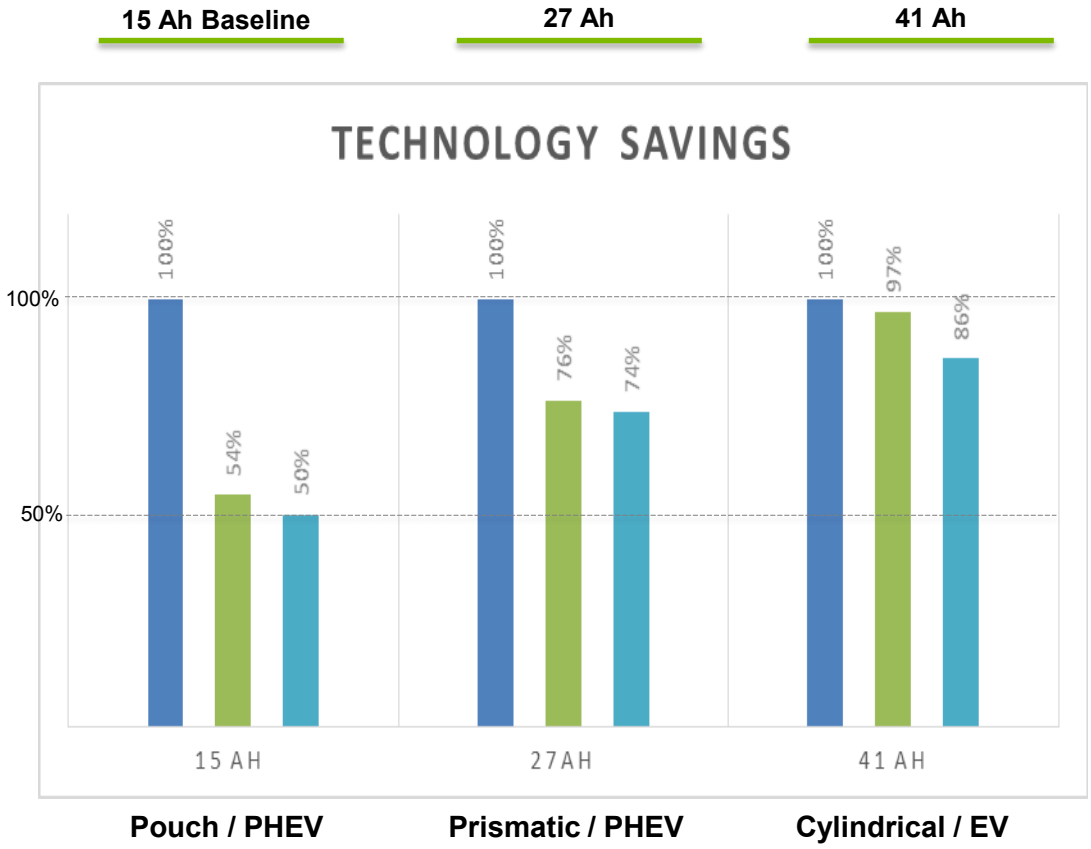
Cost Model

Model Assumptions

- *Full production: 6.5M cells*
- *Work hours: 80 hrs/week*
- *Work year: 47.5 weeks*
- *Capital depreciation: 10 years*

Technology Approaches

	Cathode	Separator	Anode
	Baseline	Baseline	Baseline
	Aqueous	Laminated	Baseline
	Dry coating	Laminated	Dry coating



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Responses to Previous Year Reviewer's Comments

Technical accomplishments

- *"The poor rate capability at continuous currents, the reviewer said, is a significant issue that needs to be addressed for these technologies to be potentially useful for Li ion battery production. The reviewer expressed the understanding that dry electrode manufacturing can be applied only to thick electrodes and it is a challenge for fabricating high-power, thin electrode. The reviewer inquired about how the project team would address that"*

  Response: Initial performance of dry electrode showed poor rate performance so that we have characterized the micro-structure of dry electrode mainly cathode using Hg porosimetry, 3D SEM and EMPA. We have developed new formulation and process to improve this performance as well. The final dry electrode shows quite promising results.

Proposed future research

- "*The reviewer recommended that validation of fabrication, power, life in the proposed 15Ah cells, as well as cost modeling be the focus of future work*"

  Response: We submitted three sets of deliverables including 15Ah integrated cells to validate developed each technologies during our project and 15Ah cell cost model as well even though there're some issues of large dimension dry cathode fabrication. We addressed the what the issues are and possible solution for the future.

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Collaboration

Entek Maxwell

- Award sub-recipient
- Leader in micro-porous membranes
- Focus on direct coated separator

Johnson Controls, Inc.

- Award prime recipient
- Leader in Lead acid and Li-ion batteries
- Focus on cell design integrating new advanced technologies from our partners, water based cathode, and fast formation.

Maxwell Technologies

- Award sub-recipient
- Leader in ultra-capacitor technology
- Focus on dry coating electrode research

University of Wisconsin - Milwaukee

- Partner in innovation
- Leading institute in material science and energy storage
- Focus on Al corrosion and wetting phenomenon of Li-ion cell, modeling, and cell characterization

Future Works

Remainder of 2015

- Evaluate final deliverables

Remaining Challenges and Barriers

- Scale-up dry cathode process
- High self-discharge rate and dV variation
- Transfer new technologies to product practically

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Summary

Relevance

- Develop integrated cell with dry electrode, direct coated separator, and fast formation to accomplish 50% cost savings while maintaining 90% performance compared to baseline design

Approach

- Dry electrode

  Improve the micro-structure and morphology of the electrode and develop the process of automated pilot line for large format cell builds

- Aqueous cathode

  Develop an additive and new formulation for mixing and coating process improvements

- Direct coated separator

  Develop roll-to-roll process for scale-up to improve lamination strength and reduce thickness variation

- Fast formation

  Develop new activation process to improve cell uniformity using step-charging and step-aging process and develop an improved detection process at low SOCs

Technical accomplishments

- Dry electrode

  The cells built with final dry electrode demonstrate 91% performance *vs*. baseline cells and 53% cost reduction *vs*. wet coating process

- Aqueous cathode

  The cells with aqueous cathode show 98% performance *vs*. baseline cells and 3.5% cost reduction compared to NMP based electrode process.

  The cells with new developed mixing process deliver promising performance and quality as well.

- Direct coated separator

  The cells show 100% performance *vs*. baseline cells and 56% cost reduction on assembly process compared to the regular PE separator.

- Fast formation

  It reduced formation lead time from 24 days to 7 days having excellent performance and detectability.

Proposed future research

- Transfer technologies to production

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